# ALPS MHD Results

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***Presented at ALPS e-Meeting***

***May 4, 2001***

# Presentation Outline

- Modeling results of MHD flow in an insulated duct
- International Collaboration on MHD for ALPS
- Future Modeling and Experiments at low-intermediate MHD interactions

# MHD FLOW IN A CIRCULAR DUCT IN A NONUNIFORM MAGNETIC FIELD

- Comprehensive, parametric three-part study of the combined effects of a non-uniform magnetic field and bending

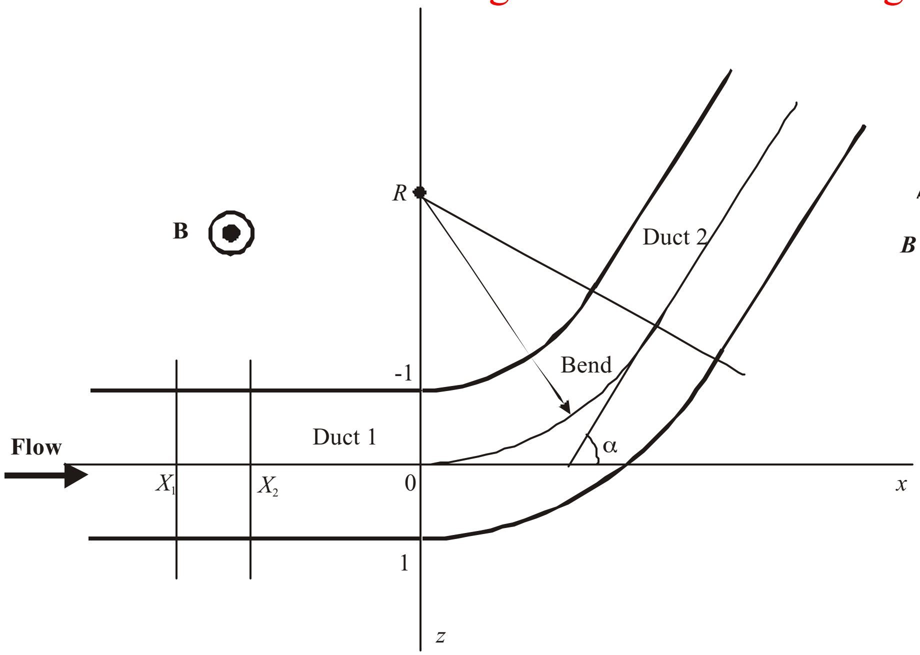



Figure 1: Bended circular duct. Magnetic field is perpendicular to the plane of the bend

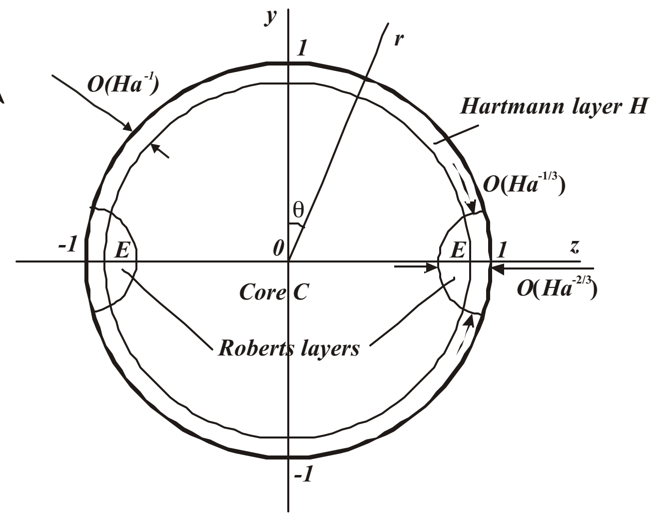



Figure 2: Duct cross-section and flow sub regions at high Ha

# PART 1 OF THE STUDY:
# STRAIGHT DUCT IN A NONUNIFORM FIELD

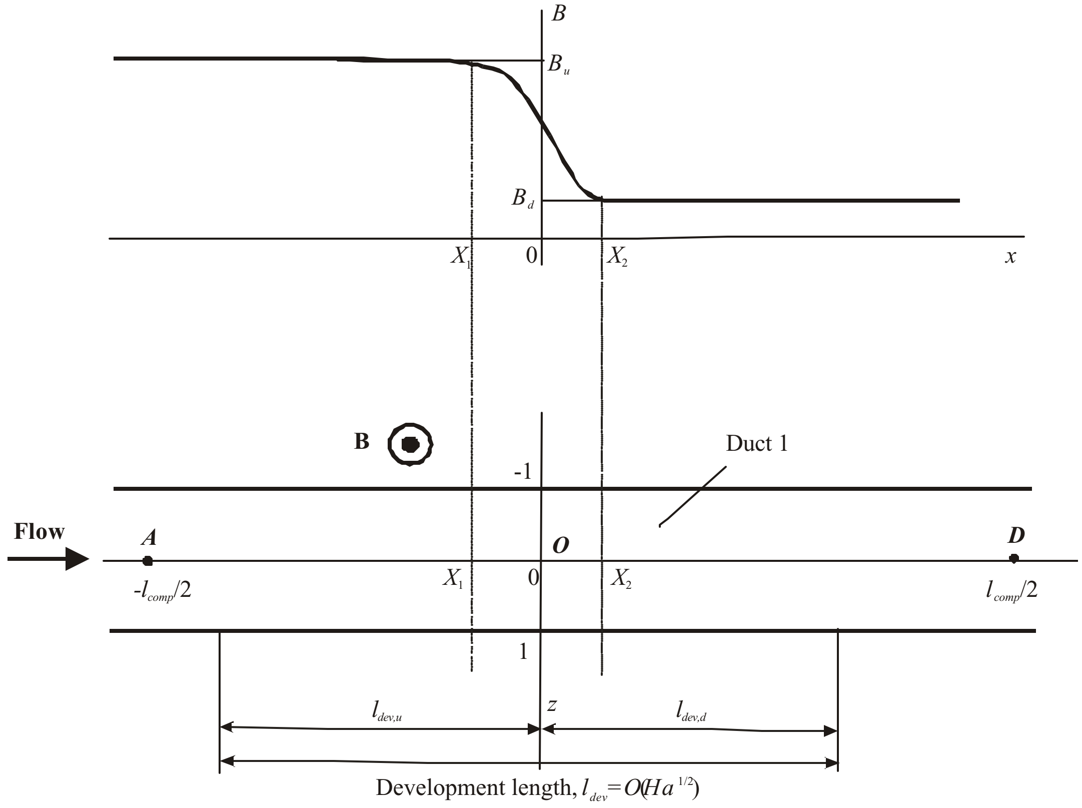



Figure 3:
Flow in a straight duct in a non-uniform field: projection onto (x,z)-plane

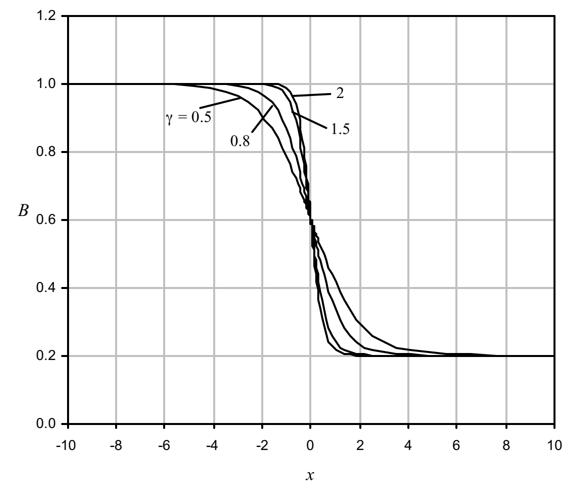
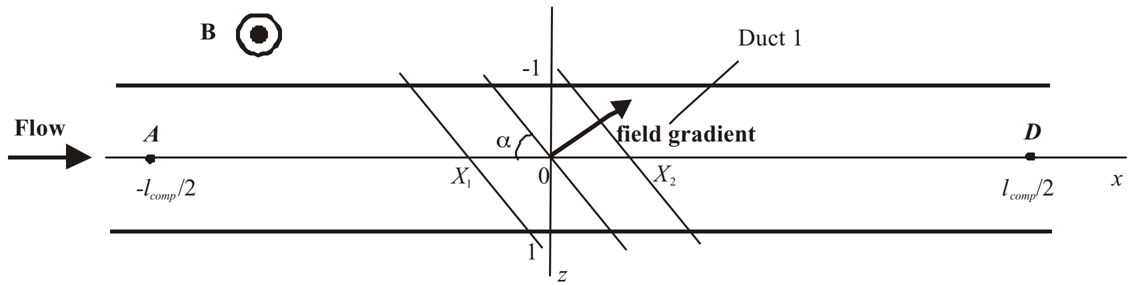



Figure 4:
"Family" of magnetic fields for different values of the field gradient γ and for $B_d$ = 0.2 (field level downstream

# PART 2 OF THE STUDY:
# INCLINATION OF THE FIELD GRADIENT



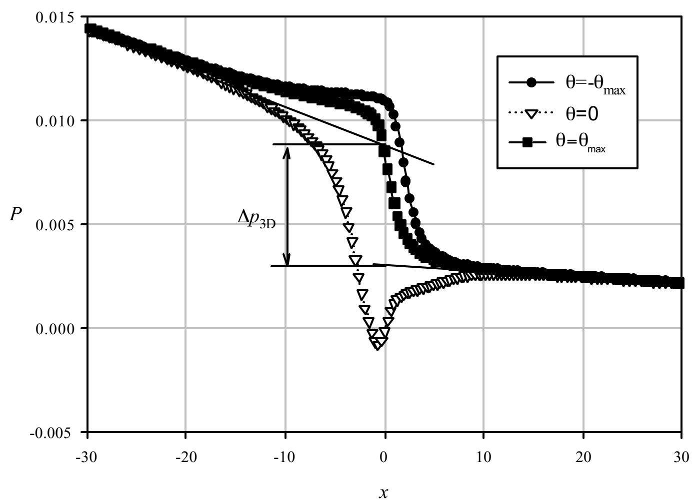
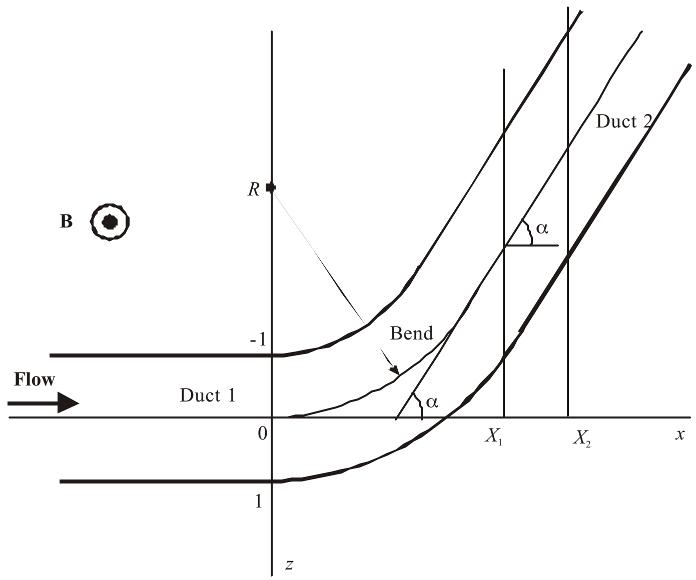




Figure 5: Development of core pressure at the duct centre (triangles), and at the side regions for z = 1 (rectangles) and for z = -1 (circles)

- The flow is no longer symmetric with respect to z
- Since the field decreases first at z = 1, pressure starts falling sooner at this position than at z = -1

# PART 3 OF THE STUDY: FLOW IN A BEND




- Incorporates flow in a straight duct, inclination of the field, and the effect of bending

- Will be finished by the end of May

# MODEL

The dimensionless parameters are:

$Ha = B_0 a \sqrt{\sigma/\rho\nu} >> 1,$ the ***Hartmann number***

$N = \sigma a B_0^2 / \rho v_0 >> 1,$ the ***interaction parameter***

- **Asymptotic approach for high Ha based on the study by Hua&Walker (1989)**
- **The flow region is divided into the core and the boundary layers at duct walls**
- **The analysis leads to two partial differential equations for the wall potential, Φ, and the core pressure, *P***
- **The equations are solved numerically by an improved finite-difference scheme**
- **The new scheme allows for modeling flows at very high Hartmann numbers ( > $10^5$ )**

# RESULTS I: WALL POTENTIAL AND CORE PRESSURE

Results below are for Ha = 7000, $B_d = 0.2$, $\gamma = 0.8$ unless stated otherwise

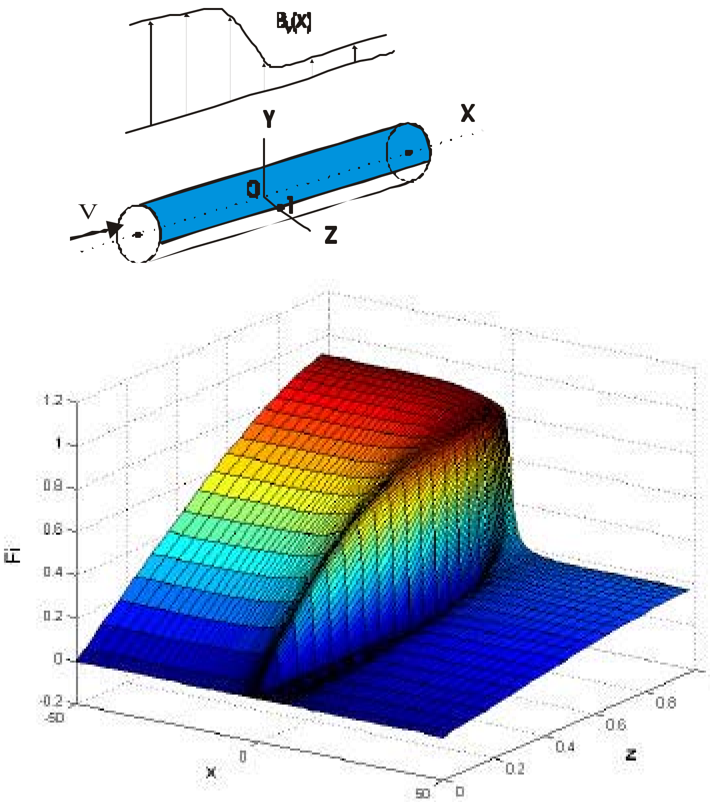



Figure 6: Wall potential

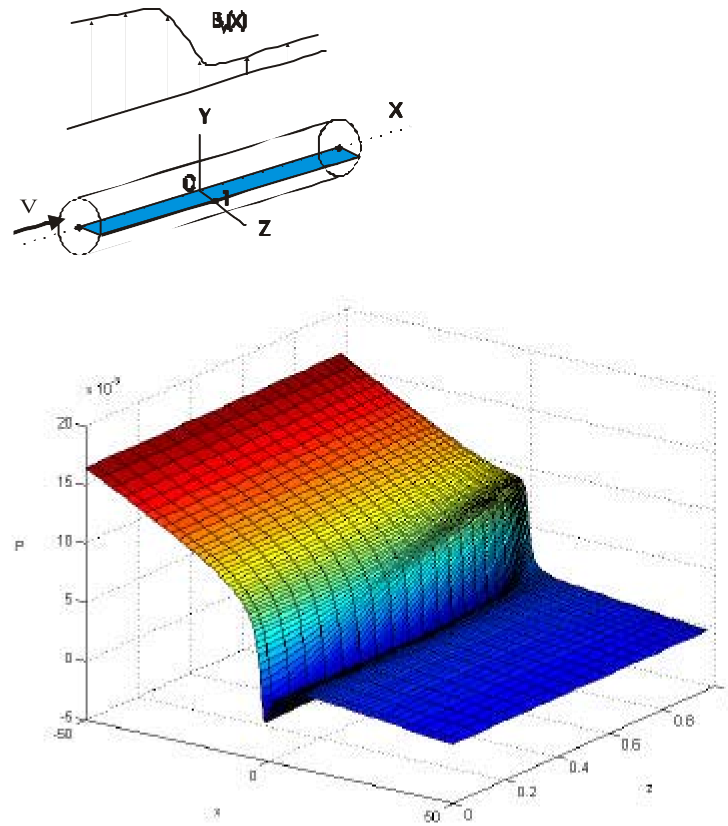
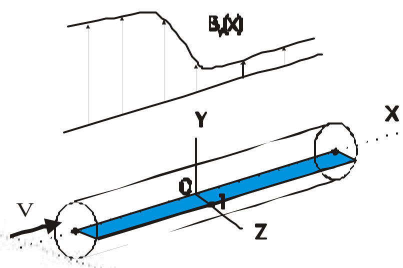



Figure 7: Core pressure

# RESULTS II: AXIAL VELOCITY AND CURRENT



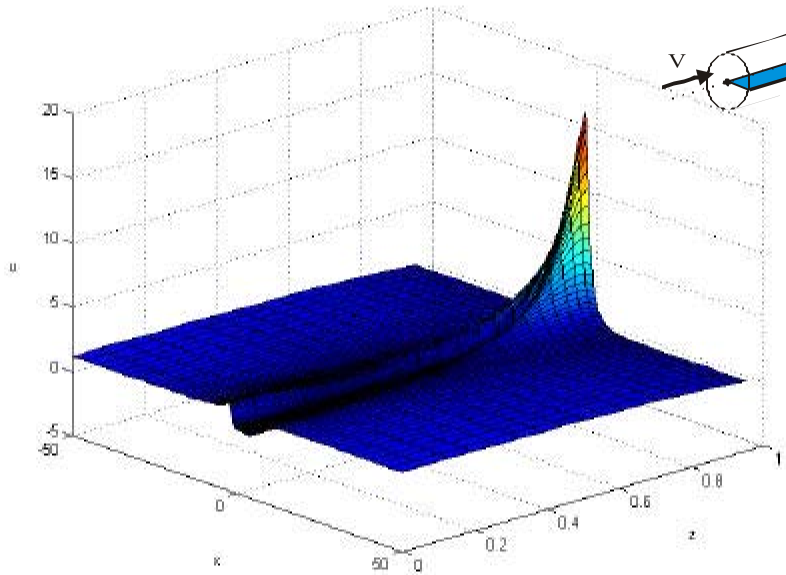



Figure 8: Axial core velocity at y = 0.
There is a stagnant zone for –1 < x < 4.5.

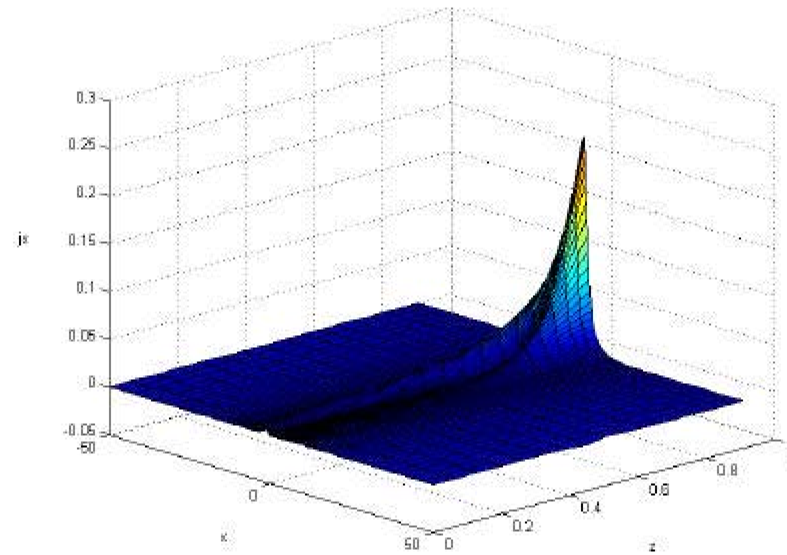


Figure 9: Axial core current

# RESULTS III: VARIATION OF PRESSURE ALONG THE DUCT

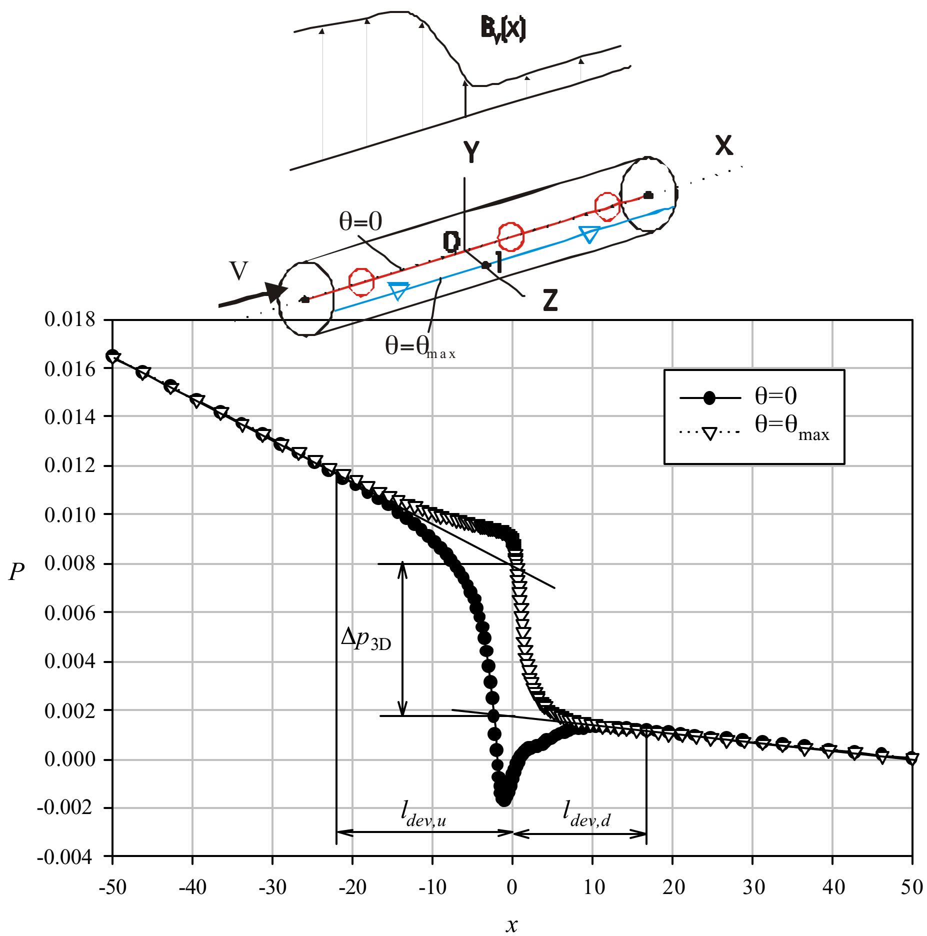



Figure 10: Development of pressure along the duct axis.

Definition of the development length, and the 3D pressure drop

Development length upstream:

$l_{dev,u} = 22$

Development length downstream:

$l_{dev,d} = 17$

3D pressure drop

$\Delta p_{3D} = 0.006$

# RESULTS IV: VARIATION OF Ha

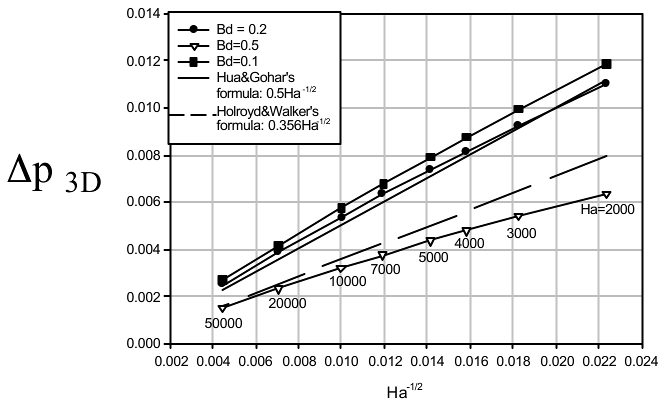



Figure 11: 3D pressure drop

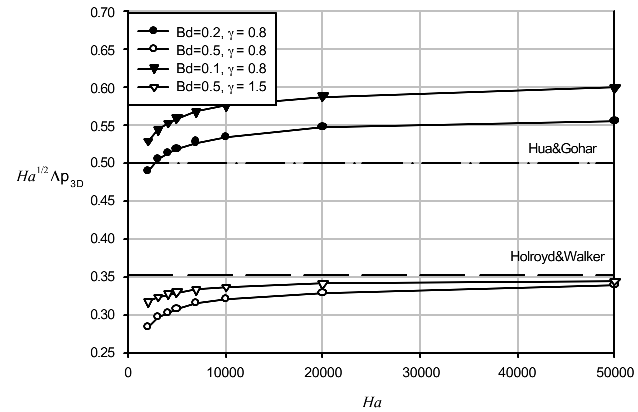



Figure 12: Scaled 3D pressure drop

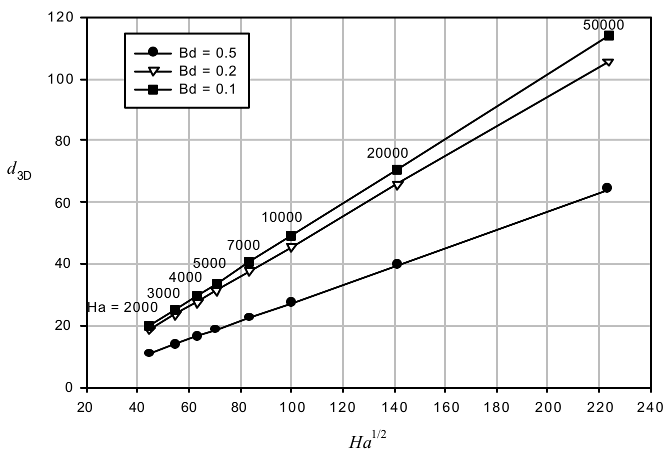



Figure 13: 3D length

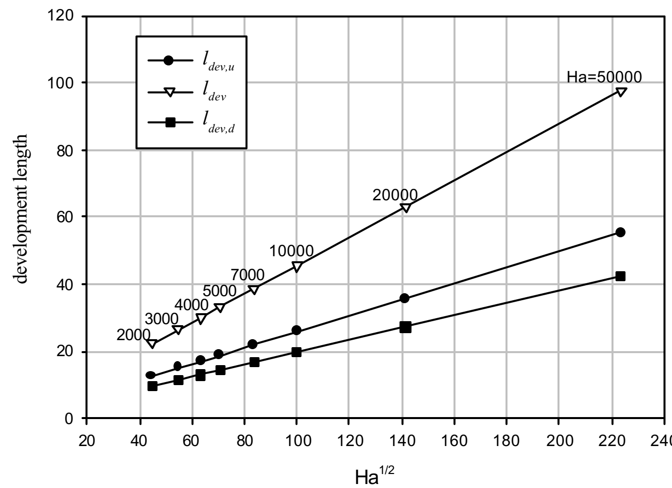



Figure 14: Development length

# RESULTS V: VARIATION OF $B_D$, FIELD LEVEL DOWNSTREAM

$\Delta p_{3D}$

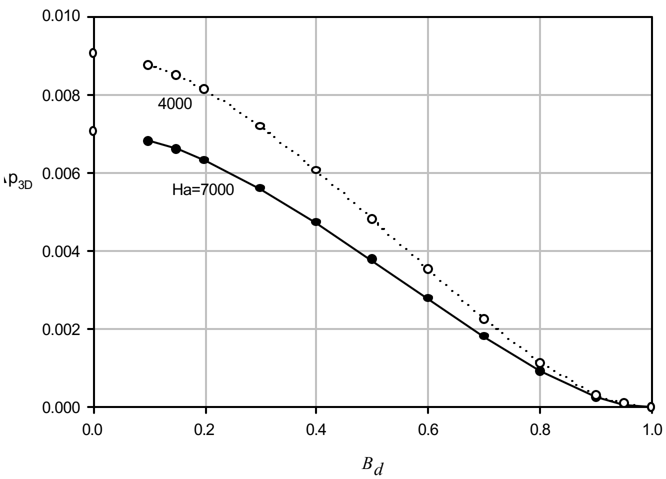



Figure 15: 3D pressure drop

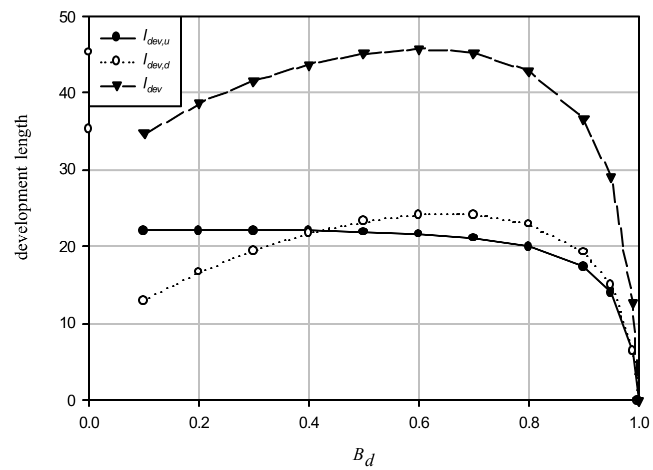



Figure 16: Development length

Overall: if Bd increases, 3D effects are strengthened

# RESULTS VI: VARIATION OF THE FIELD GRADIENT $\gamma$

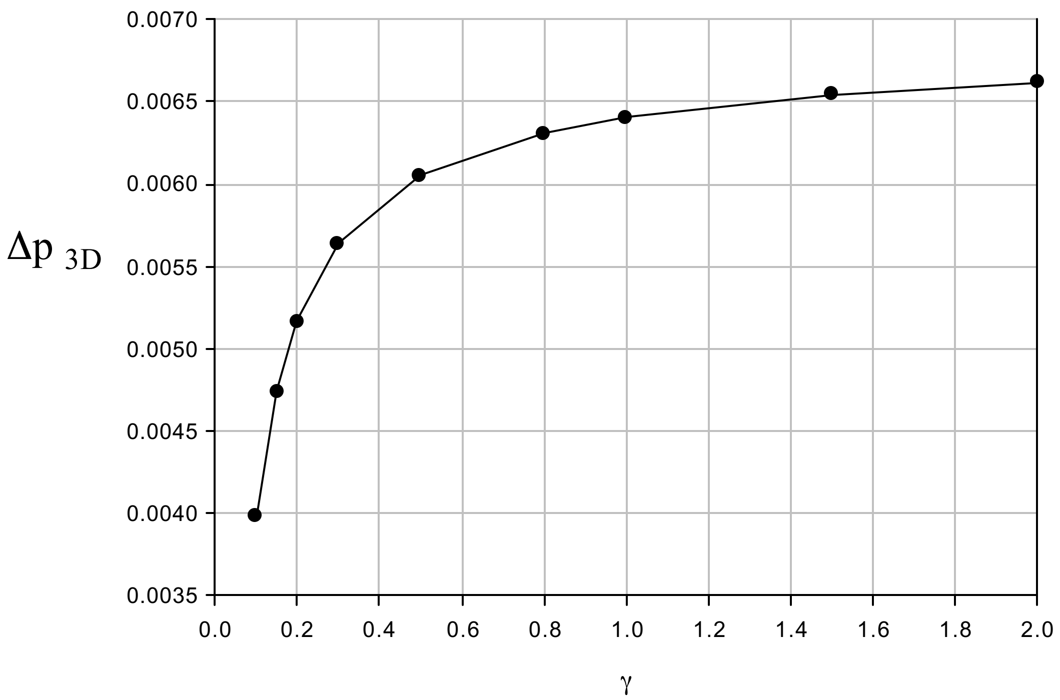



Figure 17: 3D pressure drop

Summary:

There is a strong dependence of the three-dimensional pressure drop on $\gamma$ for fields with weak gradients ($\gamma < 0.5$), and a weak dependence for fields with strong gradients ($\gamma > 1$).

# RESULTS VII: THE BENCHMARK PROBLEM (Dai-Kai Sze)

Related to inlet/outlet pipes for ARIES

- **Consider the flow of lithium in an insulating circular duct of 50cm diameter**
- **The flow enters a magnetic field, which varies from zero to 12T within a distance of 50 cm**
- **The flow velocity is 10m/s**
- **Estimate the three-dimensional MHD pressure drop**

**For this problem the values of the dimensionless parameters are:**

$$\boldsymbol{Ha = 258{,}457. \quad N = 24{,}048. \quad B_d = 0, \quad \gamma = 1.5.}$$

**Results:**

| $B_d$ | $\Delta p_{3D}$ | $\Delta p^*_{3D}$, MPa | $d_{3D}$ | $l_{dev,u}$ | $l_{dev,d}$ | $l_{dev}$ |
|---|---|---|---|---|---|---|
| 0.2 | $1.12 \cdot 10^{-3}$ | 1.35 | 245.7 | 120.41 | 93.62 | 214.03 |
| 0.1 | $1.22 \cdot 10^{-3}$ | 1.47 | 267.6 | 137.63 | 64.78 | 202.42 |
| 0 | $1.32 \cdot 10^{-3}$ | 1.59 | 289.6 | 154.85 | 35.94 | 190.79 |

# RESULTS VIII: THE EFFECT OF THE FINITE LENGTH OF THE MAGNET

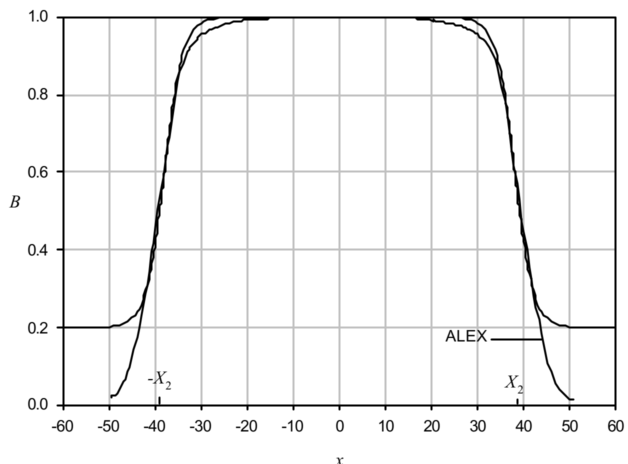



Figure 18: Field distribution in real magnets (ALEX) and the model field

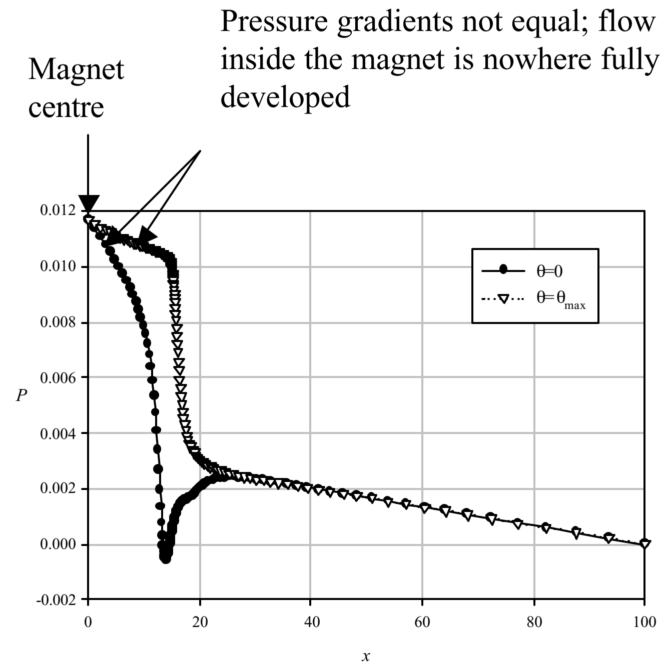



Figure 19: Development of pressure in a short magnet ($X_2 = 15$) from the centre outwards

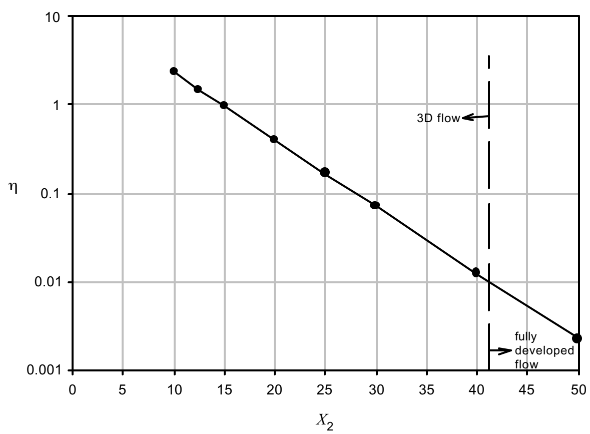
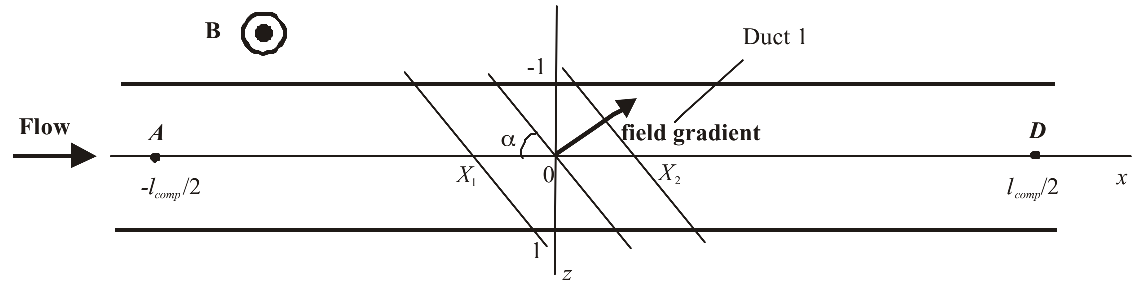



Figure 20: The measure of the fully developed flow at the centre of the magnet, η, against half magnet length, $X_2$. Flow is fully developed for $X_2 > 40$

# PART 2 OF THE STUDY:
# INCLINATION OF THE FIELD GRADIENT



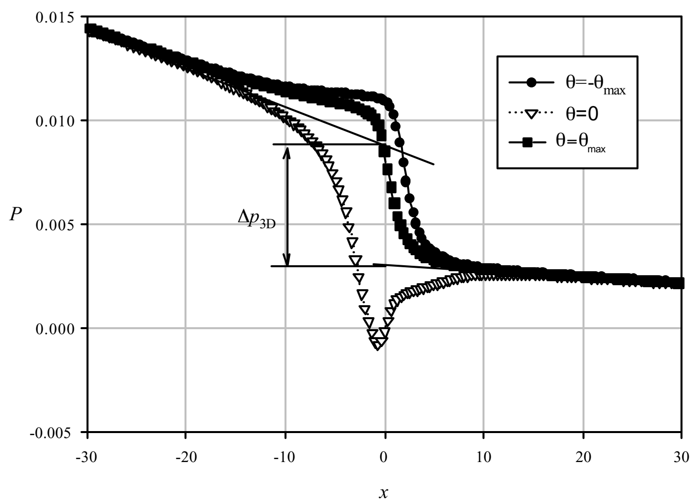




Figure 21: Development of core pressure at the duct centre (triangles), and at the side regions for z = 1 (rectangles) and for z = -1 (circles)

- The flow is no longer symmetric with respect to z
- Since the field decreases first at z = 1, pressure starts falling sooner at this position than at z = -1

# PART 2 OF THE STUDY:
# POSITIONS OF VELOCITY MAXIMA

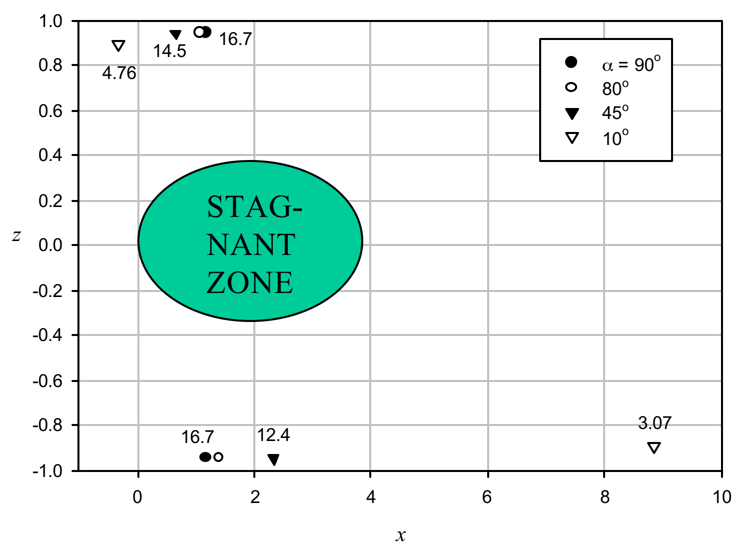
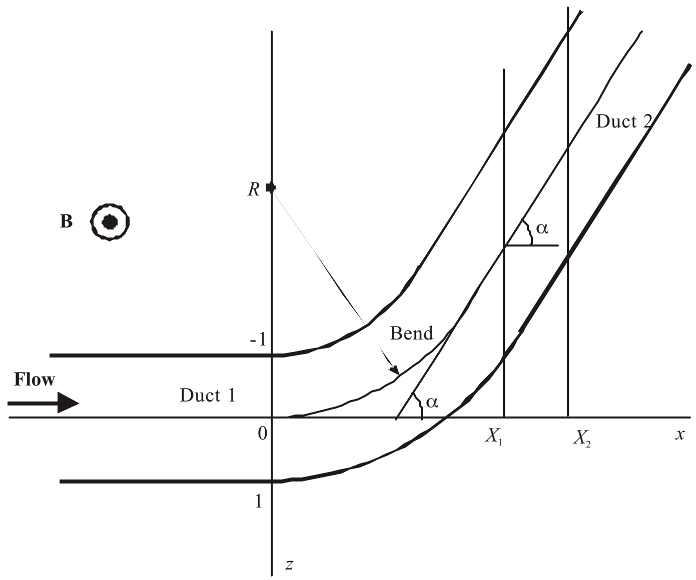



Figure 22 Positions of velocity maxima for different values of angle, $\alpha$

- For $z > 0$ velocity maximum moves upstream and towards the duct axis as $\alpha$ decreases
- For $z < 0$ velocity maximum moves downstream and towards the duct axis as $\alpha$ decreases
- Stagnant zone disappears for

  $\alpha < 80^o$
- Engineering conclusion: if one wants to avoid a stagnant zone within the flow, the duct axis ought to be inclined to the gradient of the non-uniform magnetic field

# PART 3 OF THE STUDY: FLOW IN A BEND




- Incorporates flow in a straight duct, inclination of the field, and the effect of bending

- Will be finished by the end of May

# MODELING CONCLUSIONS

- Three-dimensional effects in insulated circular ducts are significant
- High development length places a restriction on the highest value of Ha that can be reached in the laboratory experiments without violating fully developed flow conditions
- For the values of parameters relevant to fusion the development length is 10-150 duct diameters
- The three-dimensional pressure drop is equivalent to the extension of the ducts with fully developed flow by 10-100 duct diameters
- 3D pressure drop for inlet/outlet pipes for ARIES is 1.59MPa
- Current work focuses on the effect of inclination of the field gradient to the duct axis, bending and jet flow

# International MHD Collaboration for ALPS
## Status and Near Term Plans

- Parties and Institutions:
  - C. B. Reed, ANL
  - Prof. S. Molokov, Coventry Univ., UK
  - Dr. L. Buhler, FzK, Germany
  - Prof. Zengyu Xu, Southwestern Institute of Physics, Chengdu, Sichuan China
  - Dr. O. Lielausis, Inst. Physics, Latvia
  - F. Debray, NHMFL, Grenoble FR

- Meeting of Working Group on High Magnetic Fields in Coventry, UK :
  - Discuss and plan NSTX-relevant tests
  - Full day, 6/29/01, devoted to ALPS International MHD Collaboration
  - In addition to the above members, the following will attend:
    - Dr. Y. Kolsenikov, Inst. Physics, Latvia
    - Prof. R. Moreau, MADYLAM, Grenoble
    - Guy Laffont, CEA-Cadarache, FR

- Tour of NHMFL, Grenoble, FR
  - Molokov & Reed, hosted by F. Debray

- SWIP-China
  - In fall 2001, will send graduate student, Ms Maojie, to Coventry for PhD under Molokov

# Next Steps Modeling and Experiments
# For low-intermediate MHD interactions

- Produce a numerical solution for two NSTX-related problems:
  - flow in a straight insulating circular duct in a non-uniform magnetic field, and
  - straight jet appearing from a straight circular insulating duct

- Compare with asymptotic, numerical, high-Ha solution obtained previously
  - evaluate the effects of inertia

- Develop a hybrid code for the jet using a domain decomposition technique
  - extend the applicability of the resulting code to more complex geometries
  - determine complexity of problems that may be treated by the hybrid code

- Plan collaborative experiments on liquid metal jet flows (ANL-Coventry-FzK-Grenoble-Latvia-SWIP), which are relevant to both NSTX for lower magnetic fields, and to fusion reactors for high magnetic fields